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**DESCRIPTION OF THE CODE SCALID FOR  
CALCULATING THE ONE DIMENSIONAL  
SGEMP BOUNDARY LAYER**

(12)

Mission Research Corporation  
735 State Street  
Santa Barbara, California 93101

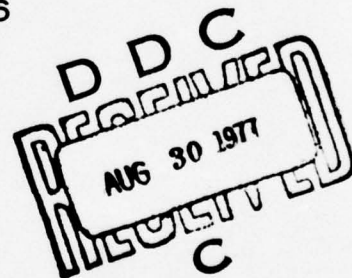
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Topical Report

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20. ABSTRACT (Continued)

Charge density, current density, field strength, potential, dipole moment, etc., are computed as a function of position and time. The code calculates with the scaled dimensionless equations of motion, assuring adequate time and space resolution.

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## SECTION 1

### INTRODUCTION

SCAL1D is a particle moving code that computes the time dependent dynamics of the electron emission SGEMP boundary layer in one Cartesian dimension. The calculation is self-consistent in that it is the correct solution to the nonlinear equations of motion using the local electric field to accelerate the electrons, but it is assumed that no skin currents flow on the target surface.

The code will accept as input an arbitrary fluence, arbitrary X-ray time history, and an arbitrary electron energy spectrum which can be read in either as a normal spectrum or as the spectrum assuming a  $\cos\theta$  angular distribution.

As the name implies, SCAL1D computes with the dimensionless scaled equations of motion which were discussed in Reference 1. The advantage of this is that the dimensionless variables are independent of the separate quantities fluence, pulse width, material yield, etc. so that the numbers computed and handled internally by the code are always of the same order of magnitude. Consequently the user need not decide on a different time step and a different cell size for each problem, thereby simplifying the use of the code and assuring a uniform accuracy and resolution.

---

<sup>1</sup> C.L. Longmire, and N.J. Carron, "Scaling of the Time Dependent SGEMP Boundary Layer", Mission Research Corporation, MRC-R-262, DNA 3975T, April 1976.



The outputs are the dimensionless electric field, potential, dipole moment, and charge and current densities as a function of position, and the spatial integral of the current density, all at selected times. In addition, the physical units of electric field, time, length, charge and current densities, etc., are printed out (in both MKS and Gaussian ESU units) so that physically correct quantities can be obtained by multiplying the dimensionless output by these units.

The results give the electron emission current in the absence of target skin currents, i.e., in the absence of any target SGEMP response. Hence, if the user inputs the correct electron emission spectrum from the material surface into vacuum, the electron space currents calculated in the code are good for a conducting target only if it can be shown that the target response (such as skin current) does not significantly alter the emission electron dynamics.

Persons interested in obtaining the code SCALID should direct the request to the Defense Nuclear Agency, Washington, DC 20305, ATTN: RAEV/SGEMP.

## SECTION 2

### BASIC IDEAS

The physical principles leading to the scaling of the boundary layer equations to obtain scaling laws and dimensionless equations were discussed in Reference 1. Here we only sketch the relevant ideas.

When X-rays are normally incident with a flux  $F(t)$  ( $\text{cal cm}^{-2} \text{sec}^{-1}$ ) on a flat plate with material yield  $Y$  (electrons/cal), electrons are ejected at a rate

$$r_0(t) = Y F(t) \text{ electrons cm}^{-2} \text{sec}^{-1} . \quad (1)$$

Let  $v$  be the normal velocity component of the electrons. Then the emission angular distribution and energy spectrum determine  $dn/dv$  (electrons  $(\text{cm/sec})^{-1}$ ), the distribution of  $v$ . The normalized normal velocity spectrum is

$$g(v) = \frac{dn/dv}{\int_0^\infty \frac{dn}{dv} dv} \quad (\text{cm/sec})^{-1} \quad (2)$$

such that  $\int g(v) dv = 1$ . The average normal velocity is

$$\bar{v} = \int_0^\infty v g(v) dv. \quad (3)$$

Let the fluence be

$$\phi = \int_0^{\infty} F(t) dt \quad \text{cal/cm}^2, \quad (4)$$

and let

$$T_h = \text{pulse full width at half maximum (FWHM)}. \quad (5)$$

be the FWHM in seconds. Then  $T_h$  is a naturally occurring characteristic time in the problem, and

$$N_1 = \frac{Y\phi}{\bar{v} T_h} \quad \text{cm}^{-3}, \quad (6)$$

is a naturally occurring number density. Similarly,

$$L_1 = \bar{v} T_h \quad \text{cm} \quad (7)$$

is a naturally occurring unit of length.

Thus the source specifies a characteristic velocity  $\bar{v}$ , time  $T_h$ , length  $L_1$ , and number density  $N_1$ . These quantities can serve as units in terms of which one can measure all dimensioned dynamical variables.

However, there is another naturally occurring unit of time, the plasma period

$$T_p = \sqrt{\frac{m}{4\pi e^2 N_1}} \quad \text{sec} \quad (8)$$

and a corresponding distance, the Debye length

$$\lambda_D = \bar{v} T_p \text{ cm.} \quad (9)$$

$T_h$  is the time scale for the emission rate to change, while  $T_p$  is the time scale for the internal electron plasma dynamics to change.

In any particle moving code that calculates the boundary layer structure, the time step  $\Delta t$  must be small compared to both  $T_h$  and  $T_p$ . In SCALID, the unit of time, UT, is chosen as the smaller of  $T_p$  and  $T_h$ ,

$$UT = \text{MIN}(T_p, T_h) \text{ sec.} \quad (10)$$

and the time step is a small fraction of UT. Real time is measured as a multiple of UT, thereby defining dimensionless time, denoted here by a prime,  $t'$ :

$$\text{Real time} = UT \cdot t' \quad (11)$$

$$\text{Dimensionless Time} = t' = \text{Real time}/UT \quad (12)$$

$$\text{Real time step} = \Delta t = \text{small fraction of UT} \quad (13)$$

$$\text{Dimensionless time step} \equiv \Delta t' = \text{small fraction of unity} \quad (14)$$

The time in the code is dimensionless time  $t'$ , and the time step is  $\Delta t'$  (called DT in the code) and is small compared to 1. Typically,  $DT = \Delta t' \approx 0.025$  is used. UT is calculated in the code, but DT is user supplied. DT usually need not vary from problem to problem.

Since the problem has only one characteristic velocity,  $\bar{v}$ , once a unit of time has been chosen (UT) the unit of length is

$$UL = \bar{v} \cdot UT \text{ cm.} \quad (15)$$



The unit of velocity is, of course,

$$UV = \bar{v} \quad \text{cm/sec} \quad (16)$$

If the X-ray pulse is not simply a power of time,  $T_h$  exists, and the unit of number density  $UN$  is  $N_1$  of Equation (6),

$$UN = N_1 \quad \text{cm}^{-3} \quad (17)$$

If the pulse continues to rise as a power of time,  $T_h$  does not exist and  $UN$  is computed as in Section 4D.

The unit of emission rate is therefore determined to be  $N_1 \bar{v}$ . The dimensionless time history  $F'(\tau)$  is defined by

$$F(t) = \frac{\phi}{T_h} F'(\tau) \quad (18)$$

where

$$\tau = t/T_h \quad (19)$$

It is normalized to unity,

$$\int_0^{\infty} F'(\tau) d\tau = 1 \quad (20)$$

and the full width at half maximum of  $F'(\tau)$  is unity. The emission rate Equation (1), can now be written

$$r_0(t) = N_1 \bar{v} F'(\tau) \quad (21)$$

so that  $F'(\tau)$  is the dimensionless emission rate.

With  $g(v)$  the normalized spectrum of Equation (2), a dimensionless spectrum can be defined as

$$g'(v') = \bar{v} g(v) , \quad (22)$$

so that

$$\int_0^{\infty} g'(v') dv = 1 , \quad (23)$$

where

$$v' = \frac{v}{\bar{v}} \quad (24)$$

is the normal component of velocity measured as a multiple of  $\bar{v}$ .

In a particle moving code, each particle on emission represents the charge emitted by all electrons with velocity, say, between  $v'$  and  $v' + \Delta v'$  and during time between  $t'$  and  $t' + \Delta t'$ . The weight attributed to such a particle is therefore

$$\Delta W = g'(v') F'(\tau) \Delta v' \Delta t' , \quad (25)$$

with

$$\tau = \frac{t}{T_h} = \frac{UT}{T_h} t' . \quad (26)$$

Equation (25) is the weight of an emitted particle.

Once emitted, the particles are moved by the dimensionless equations of motion derived in Reference 1:

$$\frac{dv'}{dt'} = a' \quad (27)$$

$$a' = -\alpha^2 \int_{x'}^{\infty} n'(x', t') dx' . \quad (28)$$

Here  $n'$  is the dimensionless number density (number density/ $N_1$ ). Equation (28) is the correct expression for the dimensionless electric field if the unit of time  $UT = T_h$ , as in Reference 1, and

$$\alpha^2 = \frac{T_h^2}{T_p^2} \quad . \quad (29)$$

In SCAL1D, the unit of time is given by Equation (10), and instead of Equation (28), the dimensionless field is given by

$$a' = - A \int_{x'}^{\infty} n'(x', t') dx' \quad , \quad (30)$$

where

$$A = \frac{(UT)^2}{T_p^2} \quad . \quad (31)$$

Equations (27) and (30) are the dimensionless equations of motion used in the code.

### SECTION 3

#### GENERAL CODE STRUCTURE

After all input quantities are read in, the space grid is set up. The space grid is used for calculating the electric field as a function of position. Since dynamical quantities are expected to vary more rapidly near the surface than farther away, the space grid has logarithmic spacing, with each cell a constant factor  $\xi$  thicker than the previous one. If many cells are used (one may use up to 500 cells),  $\xi$  must not be much larger than unity. If there are NC cells, the ratio of the thickness of the last cell,  $\ell_{NC}$ , to the first cell,  $\ell_1$ , is

$$\frac{\ell_{NC}}{\ell_1} = \xi^{NC-1} . \quad (32)$$

If NC = 500, this will be unwieldly large if  $\xi$  is greater than about 1.005, for which  $\ell_{NC}/\ell_1 \approx 12$ .

The first cell nearest the surface will be the thinnest. The first few cells should not be made too thin. They should be small compared to a Debye length (that is, small compared to unity in the code's dimensionless variables) but large enough to contain on the order of 100 particles per cell for good statistics when computing charge and current densities. (The number of particles per cell is also affected, of course, by the number NV of particles emitted every time step.) We find good results if the first cell thickness is  $\sim 0.05$  to  $0.1$ .



The input spectrum is read in as an energy spectrum with energies in keV. The input energy spectrum may be either that for a  $\cos\theta$  emission angular distribution (ICN = 0), or it may be the spectrum for the normal component of energy (ICN = 1). If the former, the spectrum is internally converted to a normal spectrum.

The spectrum is then converted to a normal velocity spectrum  $dn/dv$ , and the input energies are converted to normal velocities. The average normal velocity  $\bar{v}$  and energy are then computed.

The spectrum and velocities are now normalized, velocities (as multiples of  $\bar{v}$ ) are the dimensionless particle emission velocities. If NV energies were originally read in, there are NV particles emitted every time step. They all have weight  $1/NV$ .

Before entering the time loop, the dimensional units of length, time, velocity, electric field strength, potential, charge density, current density, etc., are computed and printed out.

The time loop is then entered, with the new particles being emitted first. Their weight is determined by the time history taken from function .FT. Then all particles are moved, using old velocities and old accelerations. New fields are then calculated at cell edges.

If the cycle is a print cycle, quantities of interest that are not needed in the particle moving loop are computed, such as current and charge densities and potentials, and are printed.

The code structure is exhibited in the flow diagram in Figure 1.

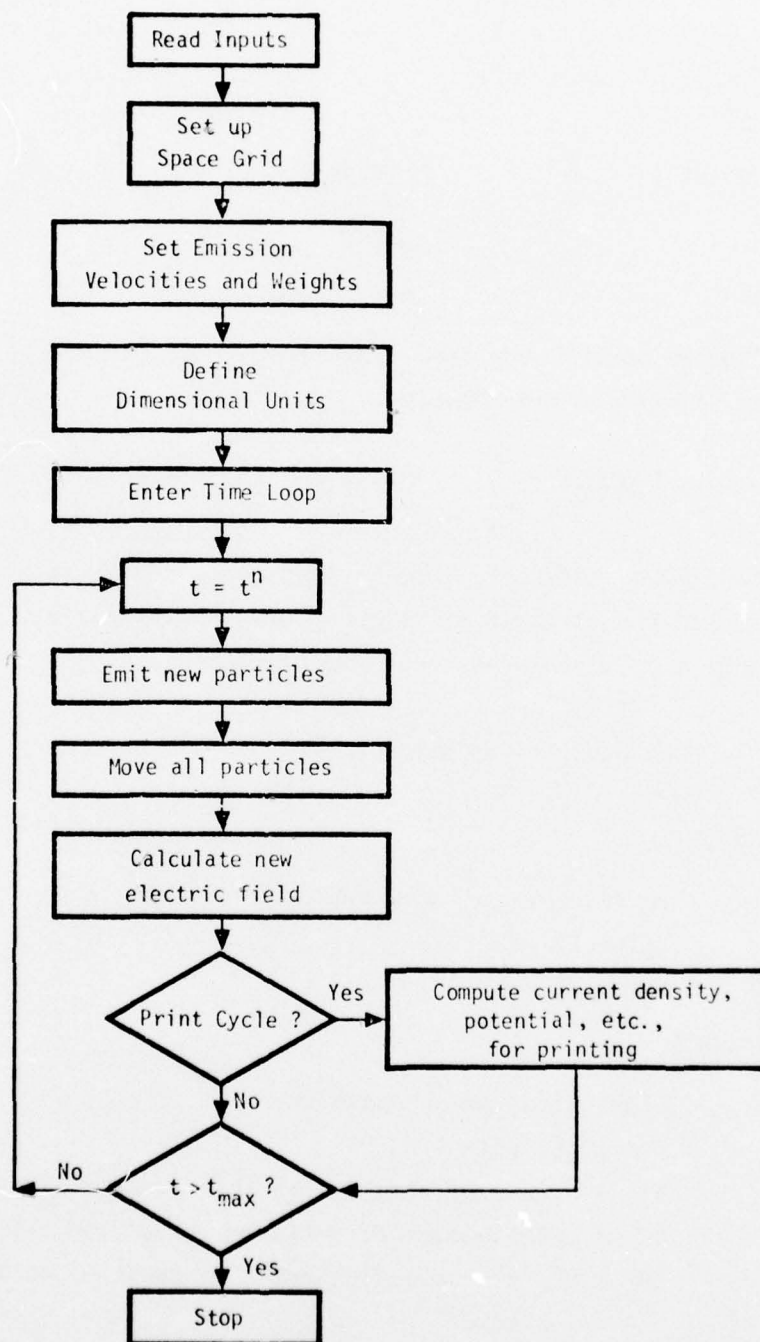


Figure 1. Flow chart of SCALID.

## SECTION 4

### INPUT

Here we discuss the input card format and the way the space grid and emission velocities are computed.

#### A. INPUT CARD FORMAT

Four basic cards are read in per problem, plus an additional NV cards specifying the electron emission spectrum if it differs from the previous problem or if this is the first problem.

The four basic cards are:

##### CARD 1

An 80 character alphanumeric title.

TITLE(I), I = 1,8

Format (8A10)

##### CARD 2

Eight fixed point parameters.

Format (14I5)

NT = number of time cycles this problem is to run

NC = total number of cells in space grid,  $\leq 500$

IR = 0 - Read electron emission spectrum on following cards

= 1 - Use same spectrum as previous problem (IR can equal 1 only if this is not the first problem)

ICN = 0 - the electron energy spectrum is for a  $\cos\theta$  angular distribution  
       = 1 - the electron energy spectrum is the normal energy spectrum  
 NV = number of spectrum points read in,  $\leq 100$   
 IT = 1, 2, 3, ... = choice of time histories, see FUNCTION FT  
       = 1 - X-ray pulse rises as a power (POW) of time  
       = 2 - symmetric triangle  
       = 3 - asymmetric triangle. Rises to peak in  $0.5 \cdot \text{FWHM}$ , falls to zero at  $2.0 \cdot \text{FWHM}$   
       = 4, 5, 6, ... - user must define a time history in FUNCTION FT  
 IP = print cycles. A printout will occur every IP cycles.  
 LP = 0 - this is last problem  
       = 1 - another problem follows

### CARD 3

Five floating point variables.

Format (8E10.3)

DT = dimensionless time step (typically  $DT \approx 0.025$ )  
 XMAX = dimensionless distance from surface to end of grid. Essentially the number of Debye lengths in the grid. (Typically  $20 \leq XMAX \leq 100$ )  
 XI = Space grid logarithmic spacing ratio,  $\geq 1.0$ . If  $XI = 1.0$  all cells are the same size. If  $XI > 1.0$ , each cell is a factor XI thicker than the preceeding one. If NC is large, XI must not be too large for practical purposes.



POW = power of time of X-ray time history (used only if  
IT = 1)

PROBNO = problem number

CARD 4

Three floating point variables.

Format (8E10.3)

YIE = material yield in electrons/calorie

FLU - If IT  $\neq$  1, FLU = X-ray fluence in calories/cm<sup>2</sup>

- If IT = 1, FLU is the coefficient determined  
(by the user) from the equation

$$\text{X-ray flux} \left( \frac{\text{cal}}{\text{cm}^2 \text{ sec}} \right) = \text{FLU} (\text{time}(\text{sec}))^{\text{POW}} . \quad (33)$$

FWHM - If IT  $\neq$  1, FWHM = X-ray pulse full width at half  
maximum in seconds.

- If IT = 1, FWHM is not used.

These four cards are read for each problem. In addition, if  
IR=0, NV more cards are read in which specify the electron energy spectrum  
in format 2E10.3. The first number on each card is the electron energy in  
keV. The second number is the value of the energy spectrum at that energy,  
in arbitrary units. The energy spectrum is normalized within the code, so  
no special units need be used on input. The correct normalization informa-  
tion is contained in YIE.

## B. SPACE GRID

The space grid is set up first. The thickness of the I-th cell is called  $XB(I)$ . The first cell is given by

$$XB(1) = XMAX \frac{(XI-1.)}{(XI^{NC}-1.)} \quad (34)$$

and thereafter,

$$XB(I) = XI * XB(I-1) , \quad I = 2, 3, \dots, NC. \quad (35)$$

An array  $SL(J)$  is defined as the distance to the J-th cell, by

$$SL(1) = 0.$$

$$SL(J) = \sum_{I=1}^{J-1} XB(I) , \quad J = 2, 3, \dots, NC+1. \quad (36)$$

The space grid is sketched in Figure 2.

Since the grid is logarithmically spaced, the bins fall at inconvenient locations for printing quantities as a function of  $x$ . Instead, output quantities are computed every 0.1 length units using an array  $K10(I)$  defined as follows. Mark every tenth length unit on the grid, as in Figure 3. Each mark will fall in some bin.  $K10(I)$  is the bin number in which the mark for  $x = 0.1 * J$  falls. For example, in Figure 3,  $K10(7) = 6$ , and  $K10(2) = 3$ , meaning 0.7 length units falls in bin 6, etc.

When computing output quantities, array  $K10$  is used to locate the bin corresponding to every 0.1 length units. Output quantities are then computed by averaging over that bin and two adjacent bins, as discussed later in Section 6.



Figure 2. Space grid with XB and SL.

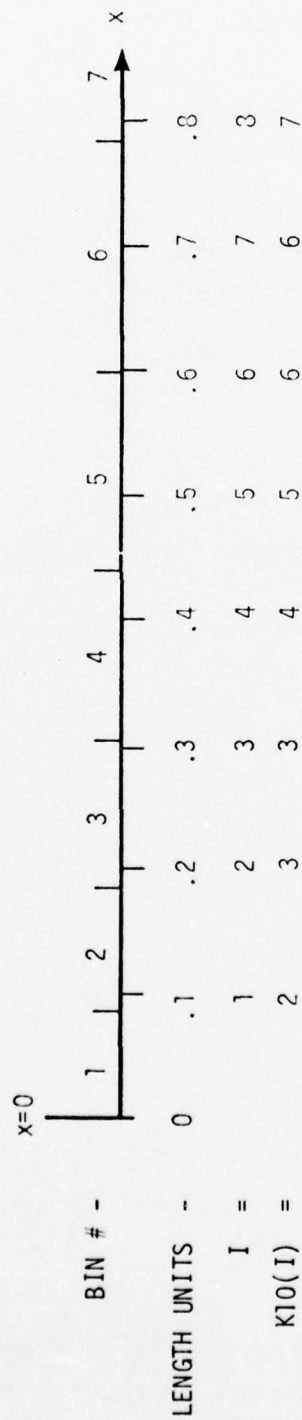


Figure 3. Space grid showing K10(I).



### C. EMISSION VELOCITIES AND WEIGHTS

As read in, the emission spectrum is an energy spectrum with energies in keV and either a normal spectrum (ICN = 1) or the energy spectrum for a  $\cos\theta$  angular distribution (ICN = 0). If the latter, the spectrum  $dn/dE$  is converted to a normal energy spectrum,  $dn/dw$ , where  $E = (1/2)mv_x^2$ , and  $w = (1/2)mv_x^2$ , where  $v_x$  is the normal velocity component, according to

$$\frac{dn}{dw} = \int_w^\infty \frac{1}{E} \frac{dn}{dE} dE \quad (37)$$

This normal energy spectrum is then converted to a velocity spectrum by

$$\begin{aligned} \gamma &= 1 + \frac{w}{mc^2} \\ v &= c \sqrt{1 - 1/\gamma^2} \\ \frac{dn}{dv} &= mv \gamma^3 \frac{dn}{dw} \end{aligned} \quad (38)$$

where we have dropped the subscript  $x$  on  $v$ . Here  $\gamma$  is the usual relativistic factor  $\gamma = (1 - v^2/c^2)^{-1/2}$ , and  $w = (\gamma - 1) mc^2$ .

The average normal velocity

$$\bar{v} = \frac{\int_0^\infty v \frac{dn}{dv} dv}{\int_0^\infty \frac{dn}{dv} dv} \quad (39)$$

is then computed, and the spectrum is normalized to unit integral, as in Equations 3 and 2. Velocities are now normalized to  $\bar{v}$ . These velocities are called  $VE(I)$ , and the spectrum  $GV(I)$ ,  $I=1, NV$ .

Finally the spectrum is divided into bins of equal area, and the velocities  $VE(I)$  are redefined as the central velocities of those bins. This gives to each emitted particle the weight  $GV(I) = 1/NV$ .

#### D. PHYSICAL UNITS

SCAL1D calculates with dimensionless quantities. To get physical results these numbers must be multiplied by the appropriate dimensional unit. These units are calculated and printed out.

If the pulse does not rise as a power of time ( $IT \neq 1$ ) then FWHM exists and the unit of number density is as in Equation (6).

$$UN = \frac{\text{Yield} \left( \frac{\text{elec}}{\text{cal}} \right) \cdot \text{fluence} \left( \frac{\text{cal}}{\text{cm}^2} \right)}{\bar{v} \text{ (cm/sec)} \cdot \text{FWHM(sec)}} \left( \frac{\text{elec}}{\text{cm}^3} \right), \quad (40)$$

and the unit of time is

$$UT = \text{MIN}(T_p, \text{FWHM}) \text{ sec}, \quad (41)$$

where

$$T_p = \sqrt{\frac{m}{4\pi e^2 \cdot UN}} \text{ sec}, \quad (42)$$

is the plasma period.

If the pulse rises as a power of time,  $t^{\text{pow}}$ , ( $IT = 1$ ) then there is no FWHM, and the unit of time is taken as<sup>1</sup>

$$UT = \left( \frac{m \bar{v}}{4\pi e^2 \cdot \text{Yield} \cdot \text{FLU}} \right)^{\frac{1}{2+\text{POW}}} \text{ sec}. \quad (43)$$

The unit of number density is

$$UN = \frac{\text{Yield FLU}}{\bar{v}} (UT)^{\text{POW}} \left( \frac{\text{elec}}{\text{cm}^3} \right) . \quad (44)$$

In Equations (43) and (44), the quantity FLU is that from Equation (33).

The unit of velocity is always

$$UV = \bar{v} , \quad (45)$$

and the unit of length is

$$UL = UV * UT , \quad (46)$$

The unit of charge density is

$$UR = 4.8 \times 10^{-10} UN \frac{\text{esu}}{\text{cm}^3} , \quad (47)$$

or

$$URM = 1.6 \times 10^{-13} UN \frac{\text{coul}}{\text{m}^3} , \quad (48)$$

in MKS units. Other units are computed similarly.

## SECTION 5

### PULSE TIME HISTORY

Three time histories are built into SCALID. The user chooses one by the value of IT on input. They are contained in FUNCTION FT.

#### IT = 1

This is for an X-ray pulse that rises in time like a power of  $t$ . The power is read in (POW) on card 3. The X-ray flux is given by Equation (33).

#### IT = 2

A symmetric triangle time history. As computed and used in FUNCTION FT its full width at half maximum is unity, and its integral is also unity. Thus it rises to value 1 at time 1 and falls to zero at time 2. The correct scale of time is taken care of when FUNCTION FT is called, using FWHM read in on card 4.

#### IT = 3

An asymmetric triangle. In FUNCTION FT its full width at half maximum is 1 as is its integral. It rises to 1 at time 0.5, and falls to zero at time 2.0. Thus the rise time is 1/4 of the full pulse length.



The user chooses one of these time histories by its shape, and reads in the real full width at half maximum as FWHM on card 4.

The coding in FUNCTION FT allows the user to add additional time histories (IT=4 or 5). As used in FUNCTION FT it must have unit integral and unit full width at half maximum.

For example, if one desires a time history with the shape of the trapezoid in Figure 4, which rises in 0.25 pulse length and stays flat to 0.5 pulse length, one would, in FUNCTION FT, choose

$$\begin{aligned} t_1 &= 0.25 t_3 \\ \text{and} \\ t_2 &= 0.5 t_3. \end{aligned}$$

Then  $t_3$  and  $F_1$  are chosen by requiring unit full width at half maximum,

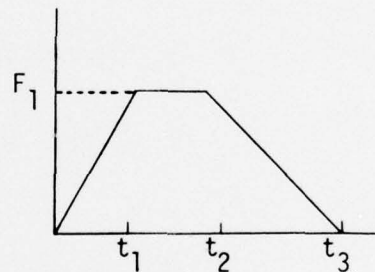


Figure 4. Trapezoid time pulse

$$\frac{1}{2} (t_3 + t_2 - t_1) = 1$$

and unit integral,

$$\frac{1}{2} F_1 (t_3 + t_2 - t_1) = 1.$$

These imply

$$t_3 = \frac{8}{5} \tag{49}$$

$$t_2 = \frac{4}{5} \tag{50}$$

$$t_1 = \frac{2}{5} \quad (51)$$

$$F_1 = 1. \quad (52)$$

These numbers specify the trapezoidal time history of Figure 4 as would be used in FUNCTION FT.

## SECTION 6

### OUTPUT FORMAT

Before the time cycle printout, an initial print shows the fixed problem parameters. The problem number, title, and first input cards are printed followed by some of the  $XB(I)$ , and  $SL(I)$ , and all of  $K10(I)$ . Then the emission velocities, spectrum, and weights are printed, followed by the plasma period (Equation (42) or (43)), the parameter  $\alpha$  of Equation (29),  $A$  of Equation (31) (called  $AL$  in the code), and a quantity  $DL$  which is one-half the particle length (finite length particles are used for the computation of charge and current densities). Finally the dimensional units of dynamical quantities are printed in mixed Gaussian esu and in MKS units.

The time cycle output begins with the cycle number and the following:

TIME	=	dimensionless time elapsed
NP	=	total number of live particles
NKILL	=	total number of particles that have been killed since time 0.
NPXMAX	=	total number of particles that have passed XMAX and been killed.
QTOT	=	total dimensionless charge per unit area outside the surface.
QR	=	total dimensionless charge per unit area that has passed XMAX.

Real time elapsed is obtained by multiplying "TIME" by the unit of time in seconds printed out at the end of the initial print. Real charge per unit area is obtained by multiplying QTOT by the unit of charge/unit area printed above, and similarly for QR.

Then the electric field and potential at the surface are printed, followed by the field and potential at every tenth length unit from the surface, out to  $x = 10.0$ . If fields and/or potentials are desired farther out than this, the print variable NPR3 may be changed in the code. The physical field and potential are obtained by multiplying the dimensionless output numbers by the units printed at the end of the initial printout.

Next, the numbers of particles in the first 100 cells are printed, together with the total charge (per unit area) in each of the first 60 cells. Then follow the charge density, current density and dipole moment every 0.1 length unit, and finally the spatial integral of the current density,

$$\int_0^{\infty} j(x,t) dx .$$

The field is computed every cycle at the edges between bins. The field printed out every 0.1 length units is obtained by simple linear interpolation from the fields at cell edges.

#### AVERAGING FOR CHARGE AND CURRENT DENSITIES

The charge density and current density are computed every 0.1 length unit by the following averaging process.

The array  $K10(I)$  shows which cell contains the point of interest, say 0.7 length units so that  $I = 7$ . For example in the space grid of Figure 3, 0.7 length units is in cell  $K10(7) = 6$ . The two adjacent cells (5 and 7) are also considered. The fractional distance  $y$  that the point  $x = 0.7$  occupies within cell 6, is computed,

$$y = \frac{x - SL(6)}{XB(6)} = \frac{0.7 - SL(6)}{XB(6)} \quad (53)$$



where

$$0 \leq y < 1. \quad (54)$$

Then the current density at  $x$ ,  $j(x)$ , is a weighted average of the current densities  $C(5)$ ,  $C(6)$ ,  $C(7)$  in cells 5, 6, and 7, respectively. The weights  $w_5$ ,  $w_6$ ,  $w_7$  given to cells 5, 6, and 7 depend on  $y$  in such a way that they have the following values when  $x$  is at an edge ( $y = 0$  or  $1$ ) or at the center of cell 6 ( $y = 1/2$ ):

$y$	$=$	0	.5	1
$w_5$	$=$	.5	.2	0
$w_6$	$=$	.5	.6	.5
$w_7$	$=$	0	.2	.5

The weights are given by the formula

$$w_5 = \frac{1}{2} (1 - y)^{p_1} \quad (55a)$$

$$w_7 = \frac{1}{2} y^{p_1} \quad (55b)$$

$$w_6 = 1 - w_5 - w_7 \quad (55c)$$

where

$$p_1 = 1.32193 \quad (55d)$$

Equations (55) interpolate between the weights given in the above table. When the point of interest,  $x$ , falls at the center of a cell ( $y = \frac{1}{2}$ ), the averaging gives three times the weight to this cell as to either adjacent cell. When  $x$  falls at the boundary between two cells ( $y = 0$ , or  $1$ ) those two cells receive equal weight.

## SECTION 7

### SAMPLE RUN

We present the results of a sample run consisting of two problems. Both are for a 5 keV blackbody X-ray spectrum incident on aluminum. The first problem has a time history which is a symmetric triangle ( $IT=2$ ) with full width at half maximum of 10 ns ( $FWHM=1\times 10^{-8}$  sec), and a fluence of  $2\times 10^{-4}$  cal/cm<sup>2</sup>. The second problem has a time history which is a continuously linearly rising X-ray flux ( $IT=1$ ,  $POW=1.0$ ), and hence there is no FWHM or fluence. The parameter FLU in the second problem is chosen from Equation (33) so that the flux is the same as the rising portion of the pulse in the first problem. In this case,  $FLU=2.0\times 10^{12}$  in units of cal/cm<sup>2</sup>/sec<sup>2</sup>. In both problems, the yield is  $YIE=2.57\times 10^{12}$  elec/cal.

The input cards for this run are shown in Figure 5. Figure 6 shows the initial print output for problem 1.0, and Figure 7 shows a sample of the time cycle output. Figure 8 shows the initial print for problem 2.0, and Figure 9 is a sample of its time cycle output.

Referring to Figure 5, we have chosen a space grid out to  $x=50.0$  length units (essentially 50 Debye lengths), and have used 350 cells with a spacing ratio  $\xi=1.004$ . The time step is 0.025 time units (essentially 0.025 plasma periods) and we print every 10 cycles. The first problem will run for 500 cycles, the second for 400 cycles. There are 32 input cards defining the spectrum. 32 particles will be emitted each time step.

In Figure 6 the initial print shows the first four data cards, then various bin sizes XB and distances SL. The full array K10 is

```

SAMPLE PROBLEM ONE.  5 KEV BB ON ALUMINUM
500 350  0  0  32  2  10  1
0.025  50.0  1.004  0.0  1.0
2.57E12  2.0E-4  1.E-8
0.15  5.447E-06
0.45  1.634E-05
1.0  3.631E-05
1.5  9.768E-06
2.0  1.178E-05
2.5  8.724E-06
3.0  9.710E-06
4.0  8.015E-06
5.0  6.562E-06
6.0  5.350E-06
7.0  4.348E-06
8.0  3.535E-06
10.0  2.518E-06
12.0  1.625E-06
14.0  1.048E-06
16.0  6.768E-07
18.0  4.390E-07
20.0  2.850E-07
22.0  1.571E-07
24.0  8.678E-08
26.0  8.286E-08
28.0  4.252E-08
30.0  2.355E-08
33.0  1.235E-08
36.0  6.527E-09
39.0  3.019E-09
42.0  2.728E-09
46.0  1.132E-09
50.0  4.714E-10
55.0  9.353E-11
60.0  3.502E-11
70.0  5.813E-12
SAMPLE PROBLEM TWO.  LINEAR RISE.
400 350  1  0  32  1  10  0
0.025  50.0  1.004  1.0  2.00
2.57E12  2.E12  0.

```

Figure 5. Data cards for sample run.





[illegible]

```

NORMAL ENERGY SPECTRUM...
5.514E+00  2.428E+00  1.506E+00  1.109E+00  9.724E+00  5.454E+00  3.877E+00  2.799E+00
2.488E+00  1.506E+00  1.109E+00  9.724E+00  5.454E+00  3.877E+00  2.799E+00  1.711E+00
2.488E+00  1.506E+00  1.109E+00  9.724E+00  5.454E+00  3.877E+00  2.799E+00  1.711E+00
1.093E+00  1.506E+00  1.109E+00  9.724E+00  5.454E+00  3.877E+00  2.799E+00  1.711E+00
3.071E+00  1.506E+00  1.109E+00  9.724E+00  5.454E+00  3.877E+00  2.799E+00  1.711E+00
4.324E+00  1.506E+00  1.109E+00  9.724E+00  5.454E+00  3.877E+00  2.799E+00  1.711E+00

VELOCITIES AND NORMAL VELOCITY SPECTRUM ARE
VELOCITIES (CM/SEC)***
7.250E+00  1.270E+00  2.202E+00  2.645E+00  7.250E+00  1.270E+00  2.202E+00  2.645E+00
5.855E+00  6.385E+00  5.855E+00  5.855E+00  5.855E+00  6.385E+00  5.855E+00  5.855E+00
9.215E+00  9.215E+00  1.228E+00  1.228E+00  1.228E+00  1.228E+00  1.228E+00  1.228E+00
1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00

NORMAL VELOCITY SPECTRUM
2.270E+00  3.174E+00  1.944E+00  1.824E+00  1.824E+00  1.824E+00  1.824E+00  1.824E+00
5.815E+00  5.815E+00  5.815E+00  5.815E+00  5.815E+00  5.815E+00  5.815E+00  5.815E+00
6.385E+00  6.385E+00  6.385E+00  6.385E+00  6.385E+00  6.385E+00  6.385E+00  6.385E+00
4.110E+00  4.110E+00  4.110E+00  4.110E+00  4.110E+00  4.110E+00  4.110E+00  4.110E+00
1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00

INTEGRAL OF THIS SPECTRUM FROM VELOCITY TO VELOCITY IS 5.1261E+00
AVERAGE NORMAL VELOCITY IS 2.638E+00 (CM/SEC)
AVERAGE NORMAL ENERGY IS 2.641E+00 (KEV)

NORMALIZED VELOCITIES AND SPECTRUM***
VELOCITIES
2.270E+00  3.174E+00  1.944E+00  1.824E+00  1.824E+00  1.824E+00  1.824E+00  1.824E+00
5.815E+00  5.815E+00  5.815E+00  5.815E+00  5.815E+00  5.815E+00  5.815E+00  5.815E+00
6.385E+00  6.385E+00  6.385E+00  6.385E+00  6.385E+00  6.385E+00  6.385E+00  6.385E+00
4.110E+00  4.110E+00  4.110E+00  4.110E+00  4.110E+00  4.110E+00  4.110E+00  4.110E+00
1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00

SPECTRUM
1.211E+00  8.294E+00  6.331E+00  5.824E+00  5.824E+00  5.824E+00  5.824E+00  5.824E+00
1.512E+00  9.673E+00  5.966E+00  2.273E+00  2.273E+00  2.273E+00  2.273E+00  2.273E+00
1.185E+00  7.513E+00  3.985E+00  2.122E+00  2.122E+00  2.122E+00  2.122E+00  2.122E+00
1.755E+00  7.513E+00  3.985E+00  2.122E+00  2.122E+00  2.122E+00  2.122E+00  2.122E+00

EMISSION VELOCITIES AFTER EQUALIZING HEIGHTS...
8.274E+00  1.270E+00  2.202E+00  2.645E+00  8.274E+00  1.270E+00  2.202E+00  2.645E+00
5.855E+00  6.385E+00  5.855E+00  5.855E+00  5.855E+00  6.385E+00  5.855E+00  5.855E+00
1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00  1.335E+00
2.127E+00  3.027E+00  3.027E+00  3.027E+00  3.027E+00  3.027E+00  3.027E+00  3.027E+00

EMISSION HEIGHTS...
3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00
3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00
3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00
3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00  3.125E+00

PLASMA PERIOD = TP = 4.215E+00 (SEC)
ALPHA = FWHM/TP = 2.492E+00
AL = (UT/TP)*0.2 = 1.802E+00
DL = 8.008E+00

```

Figure 6 (Continued). Initial printout for problem 1.0.

	UNIT OF
	---- --
TIME	" 4.015E-09 SEC
LENGTH	" 1.889E-01 CM
VELOCITY	" 1.035E-01 M
	" 2.619E-09 CM/SEC
CHARGE/UNIT AREA	" 9.910E-02 ESU/CM**2
	" 3.307E-07 COUL/M**2
ELECTRIC FIELD	" 1.248E-02 ESU
POTENTIAL	" 3.715E-04 VOLTS/M
	" 1.319E-01 ESU
NUMBER DENSITY	" 3.950E-03 VOLTS
	" 1.949E-07 /CM**3
CHARGE DENSITY	" 1.949E-03 ESU/CM**3
	" 3.122E-06 COUL/M**3
CURRENT DENSITY	" 8.235E-04 ABAMPS/CM**2
	" 6.235E-01 AMPS/M**2
CURRENT INTEGRAL	" 8.722E-03 ABAMPS/CM
	" 8.722E-08 AMPS/M
DIPOLE MOMENT	" 1.652E-06 ESU/CM
	" 3.532E-08 COUL/M

Figure 6 (Continued). Initial printout for problem 1.0.







```

SCALD PROBLEM NUBER 2.000
SAMPLE PROBLEM TWO, LINEAR MISE.

NT NC IP ICN NV IT IP LP
400 350 1 2 32 1 10 2

DT
2.000E+02 5.000E+01 1.000E+00 1.000E+00 2.000E+00
XMAX
X1
X2
X3
X4
X5
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Figure 8. Initial printout for problem 2.0.



IT # 1  
 X-RAY FLUX IS PROPORTIONAL TO T\*\* 1.0000  
 THERE IS NO FLUENCE OR FWHM

	UNIT OF
	---- --
TIME	5.443E-09 SEC
LENGTH	1.436E-01 CM
VELOCITY	1.436E-01 M
	2.436E-09 CM/SEC
CHARGE/UNIT AREA	7.314E-02 ESU/CM**2
	2.424E-07 COUL/M**2
ELECTRIC FIELD	9.191E-01 ESU
POTENTIAL	2.755E-04 VOLTS/M
	1.319E-01 ESU
NUMBER DENSITY	3.955E-33 VOLTS
	1.861E-07 /CM**3
CHARGE DENSITY	5.095E-03 ESU/CM**3
	1.699E-06 COUL/M**3
CURRENT DENSITY	4.482E-04 ABAMPS/CM**2
	4.482E-01 AMPS/M**2
CURRENT INTEGRAL	6.434E-03 ABAMPS/CM
	6.434E-06 AMPS/M
DIPOLE MOMENT	1.258E-03 ESU/CM
	3.592E-08 COUL/M

Figure 8 (Continued). Initial printout for problem 2.0.





Figure 9 (Continued). Time cycle print for problem 2.0.

printed next, showing for example that  $x = 2.4$  occurs in cell 35 (between SL(35) and SL(36)). The input spectrum is printed first as read in and then after conversion to a normal energy spectrum. The spectrum is then converted to a normal velocity spectrum and printed again. The average normal velocity is computed and is used as the unit of velocity. The velocities and spectrum are then normalized and printed again. Finally, equal weights are chosen for the emission particles, and their velocities are printed.

The plasma period, computed by Equation (8) or (42), the parameter  $\alpha$  of Equation (29), and the quantity  $A$  of Equation (31), (called AL in the code) are then printed together with DL. DL is one-half of the particle length. Particles are given a length of 0.16 length units (essentially 0.16 Debye lengths) for the purpose of computing their charge and current densities more smoothly.

Finally the physical units are printed in Gaussian cgs and in MKS units. Quantities printed in the time cycle output must be multiplied by the appropriate dimensional unit to obtain the physical result. For example, the unit of time is 4.015 ns, the unit of electric field is 37.35 kV/m (or 1.246 esu), and the unit of length is 10.59 cm.

As a sample of the time cycle output, we show cycle 130 of problem 1.0 in Figure 7. This is at time  $3.25 \times 4.015$  ns, or 13.05 ns. There are 3364 live particles. A total of 796 have been killed since the start of the problem, but none has passed XMAX. The total charge is 1.507 charge units, or  $4.984 \times 10^{-7}$  coulomb/m<sup>2</sup>, obtained by multiplying by the unit of charge/unit area. The surface field is  $1.507 \times 37.35$  kV/m = 56.29 kV/m.

The printout for the field every 0.1 length unit shows that at, say, 0.4 length units from the surface (4.24 cm) the field strength has dropped to  $0.8753 \times 37.35 = 32.69$  kV/m.

The potential is measured from zero at the surface. At 10.59 cm (1 length unit), for example, it has risen to  $0.8533 \times 3.955 \text{ kV} = 3.375 \text{ kV}$  as shown in the printout.

The next group of numbers shows how many particles are in each cell. There are 285 in the first cell, 221 in the second, etc. The charge (per unit area) in the first several bins is printed next.

The charge density and current density every 0.1 length unit are printed next in dimensionless form. The first number printed is at 0.1 length unit (1.059 cm) from the surface, not at the surface. The surface charge and current densities are not computed by the code. Thus at 130 cycles, the charge density at 1.059 cm is  $2.015 \times 3.122 \times 10^{-6} = 6.29 \times 10^{-6} \text{ Coul/m}^3$ , and the current density is  $0.1369 \times 82.35 = 11.27 \text{ Amps/m}^2$ .

The electron number density can also be obtained from the dimensionless charge density output by multiplying by the unit of number density ( $1.949 \times 10^7 \text{ elec/cm}^3$ ), showing, for example, that at 0.6 length units (6.35 cm) the number density is  $0.6729 \times 1.949 \times 10^7 = 1.31 \times 10^7 \text{ cm}^{-3}$ .

The dipole moment (per unit surface area) contributed by all electrons out to  $x$ ,

$$P = \int_0^x x \rho(x) dx$$

is printed next. Here the first number is at the surface,  $x=0$ , and so is 0. At, say, 0.7 length units (7.41 cm) the dipole moment is seen to be  $0.2212 \times 3.502 \times 10^{-8} = 7.75 \times 10^{-9} \text{ Coul/m}$ . Out to 9.9 length units it is  $1.511 \times 3.502 \times 10^{-8} = 5.29 \times 10^{-8} \text{ Coul/m}$ .



Finally, the integral of the current density,

$$CI = \int_0^{\infty} j(x,t) dx$$

is printed, having the value  $0.8625 \times 8.722 = 7.52$  Amps/m.

The initial print for problem 2.0 is shown in Figure 8. The XB, SL, and K10 arrays are the same, and the spectrum is the same. The plasma period in this case is computed by Equation (43) with POW = 1.0, and has a slightly different value than in problem 1.0. Similarly, the units of length, number density, etc. are not exactly the same.

We show the output for cycle 50 in Figure 9. It is at time 1.25 units = 6.804 ns. The fastest emitted particle had velocity 3.827 units and so will not have travelled farther than 4.78 length units by this time. Hence, the field beyond 4.7 length units is still 0, and the printout shows no particles beyond the 64-th cell. Otherwise the interpretation of quantities is the same as for the previous problem.

Problem 1.0 ran for 500 cycles and moved a maximum of 3542 particles (at cycle 190). Problem 2.0 ran for 400 cycles and moved a maximum of 2500 particles (at cycle 110). Total CP time for both problems on a CDC 7600 was 41.4 sec.

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